Exploiting Computational Slack in Protocol Grammars

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PH-Neutral 0x7da
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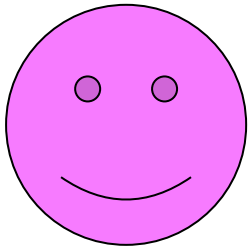
What This Talk Is Not

- A tool
  - Yet
- A library
- A framework
- An all-in-one security solution

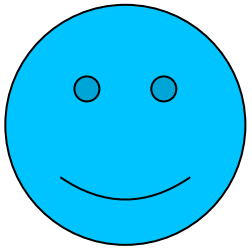
But it is…

- A methodology for implementing protocols
- A methodology for attacking protocols
- A new paradigm for thinking about protocol design
  - …with some very old roots

The Classic Communications Model

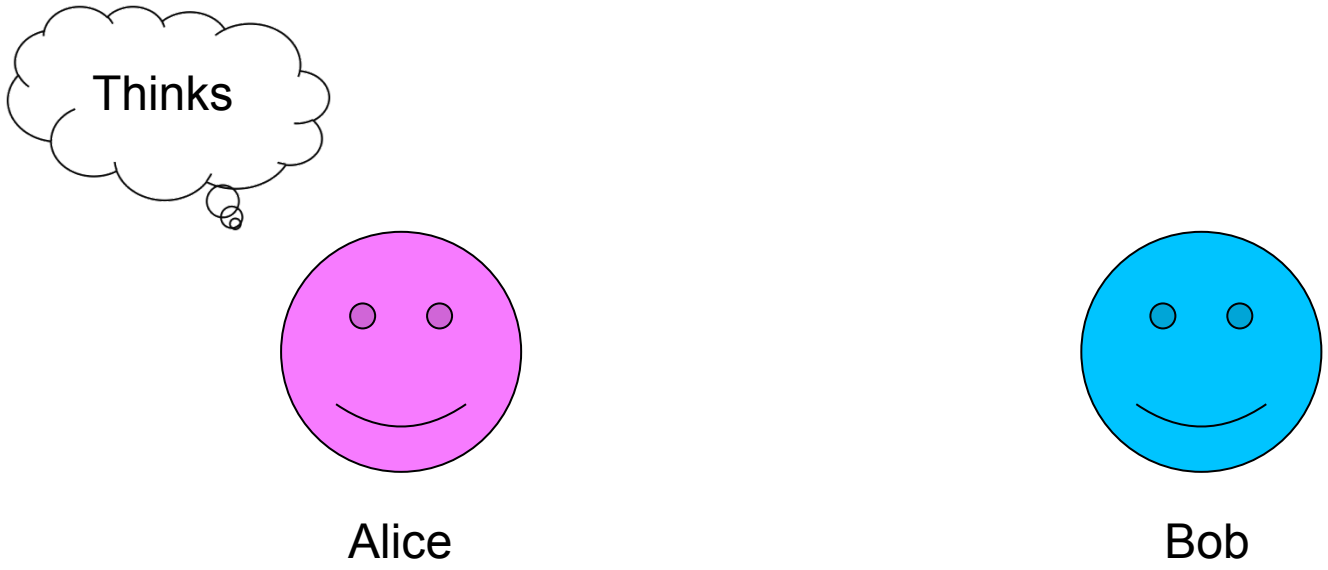


Alice

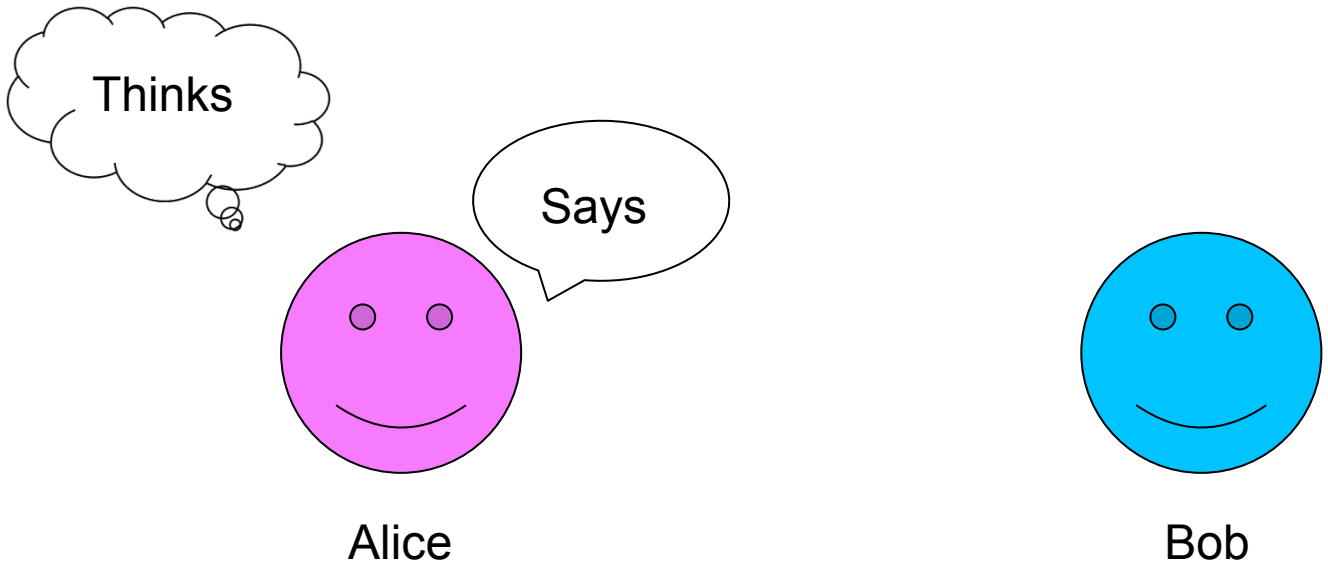


Bob

The Classic Communications Model



The Classic Communications Model



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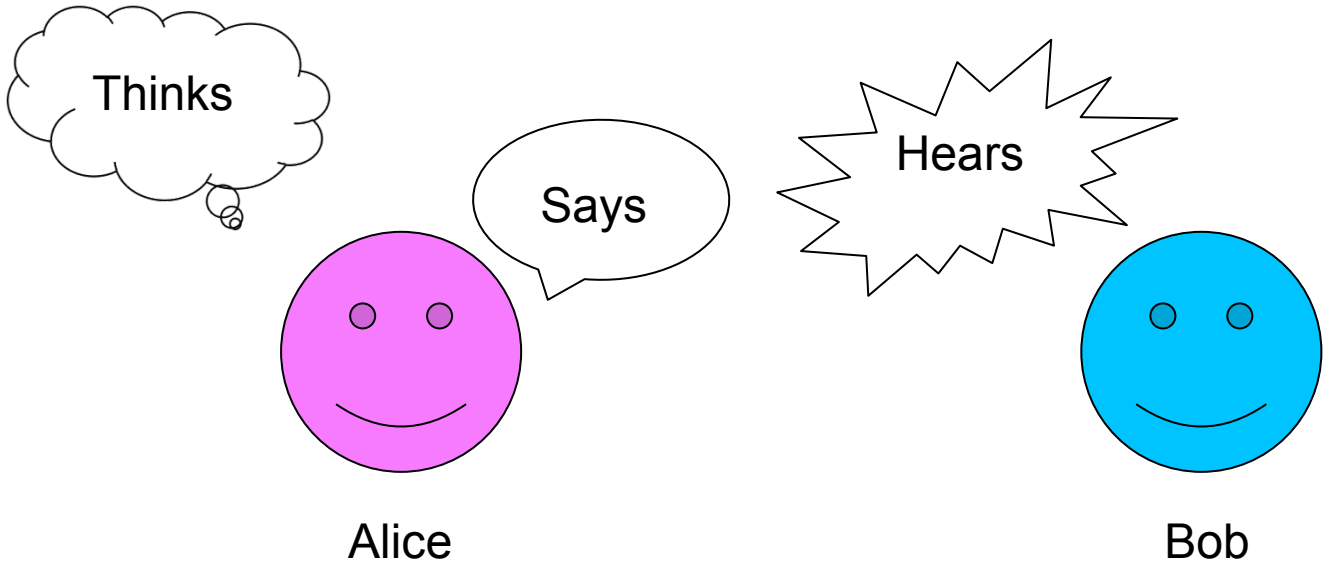
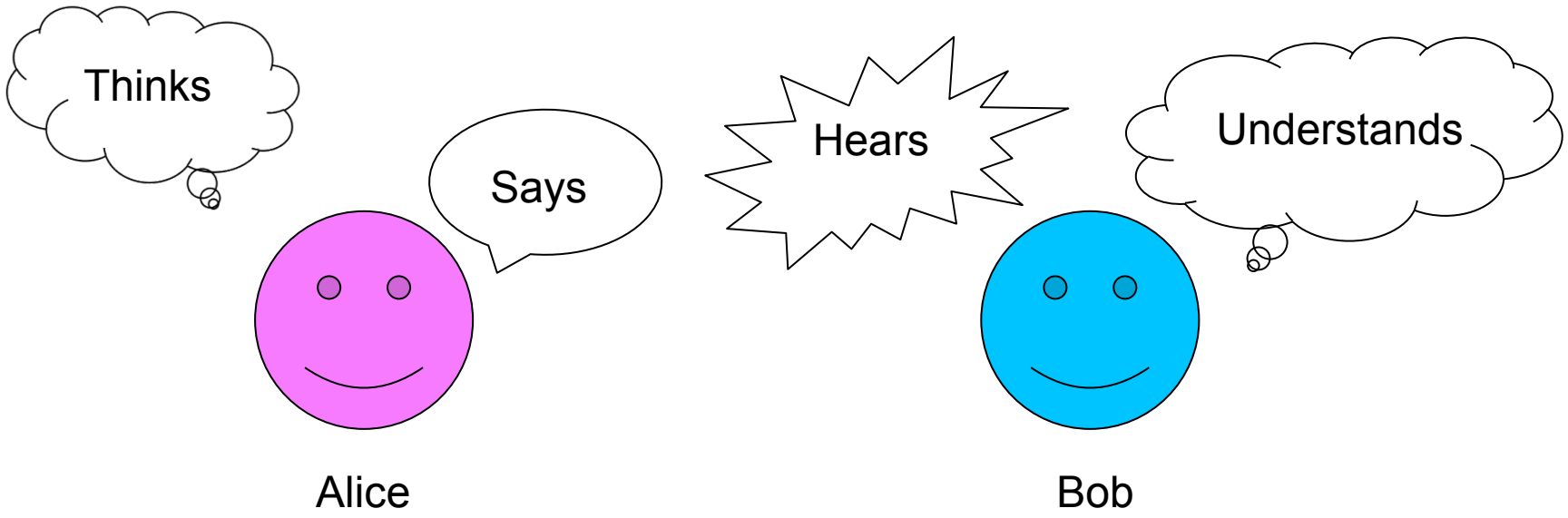
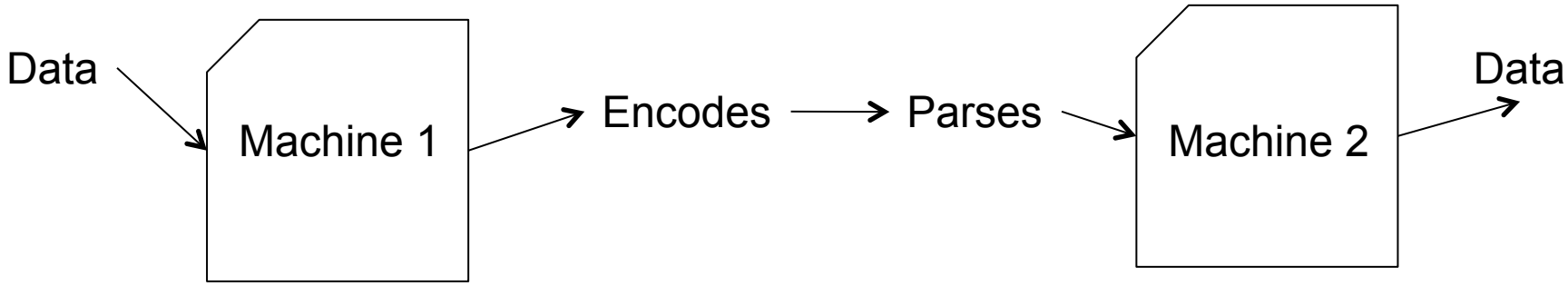


The Classic Communications Model



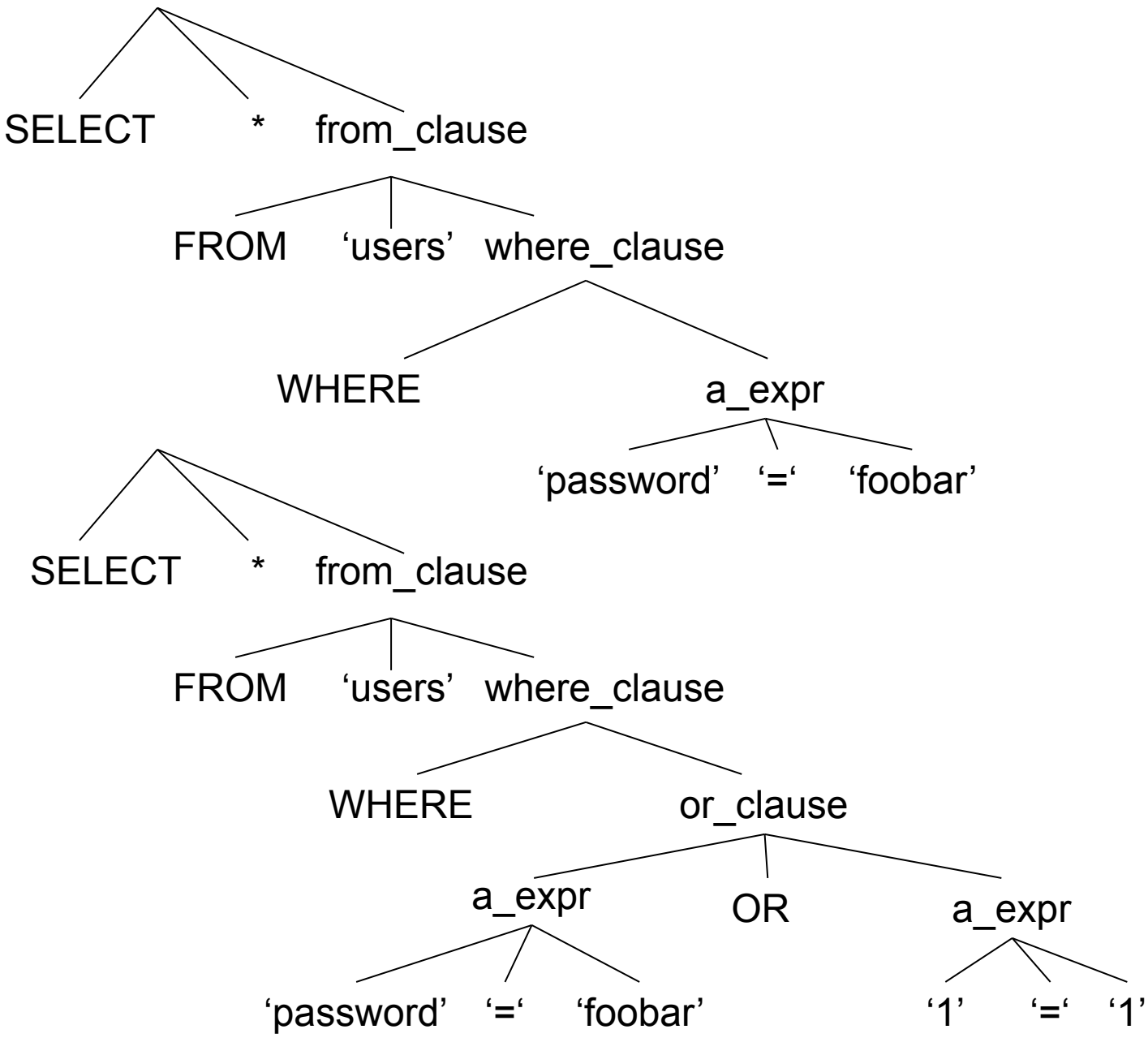
…applied to data



Keep this in mind.

Background

- 2005: Dejector
- SQL injection = mismatch between expected and input parse trees (regex/whitelist fail)
- Compare parse tree of input string with parse tree of expected “exemplar” string
- Differing nodes in input parse tree indicate clauses injected by attacker
    - Malicious OR clause (“OR 1=1”)
    - Malicious commands (“; DROP DATABASE; --”)


SELECT
*
from_clause
FROM
‘users’
where_clause
WHERE
a_expr
‘password’
‘=‘
‘foobar’
SELECT
*
from_clause
FROM
‘users’
where_clause
WHERE
or_clause
a_expr
OR
a_expr
‘password’
‘=‘
‘foobar’
‘1’
‘=‘
‘1’

Lessons from Dejector

- Trying to validate strings in a context-free language using regular expressions doesn't work
- More generally: you must validate with a computational mechanism at least as strong as the language being validated (minimum validation strength)
- Syntactic differences produce semantic differences
  - Parsers are the gateway to code execution

From context-free to context-sensitive

- 2006 CRYPTO rump session: Bleichenbacher PKCS#1 padding attack
  - Signatures padded to the width of the modulus
  - Number of padding bytes varies as a function of hash algorithm and modulus
  - Decrease the number of padding bytes, add unchecked garbage after hash, forge signature for e=3 (or 5?) [$2^{16}+1$ is plenty safe]
- PKCS#1 is context-sensitive, so parse tree comparison alone doesn't work
  - But an attribute grammar comparison does

The Classic Communications Model

- What's said: A signature that is strictly ungrammatical
  - Signature is too long, contains nonsense that shouldn't parse
  - Padding bytes are too short
- What's heard: A string with the correct overall length, possibly including some number of padding bits
- What's understood: A valid signature

Semantic Distinctions

- What we learned from Bleichenbacher:
  - If you rely on an implementation that can interpret an invalid string as valid, you lose.
  - We can validate context-sensitive languages
- Scripting languages, message formats, file formats, network protocols – all formal languages.
  - ...more or less. (ASN.1, ECMAscript = less.)
- Each implementation is its own dialect.
  - “Mutually intelligible,” in linguistics terms.

Deconstructing the Attack Surface

- What the sender means and what the recipient interprets are not necessarily the same thing
- Parsing variations lead to ambiguous meaning
  - Implementation A intends for a string to represent BIGINT, but implementation B parses it as int32
  - Implementation A deletes null bytes, but implementation B parses them as terminators
- Users don't notice what they don't do themselves
  - Implementation-to-implementation communication is more important than user-to-implementation communication!

Methodology

- Consider the formal grammar (as far as possible)
- Examine implementation details
  - How do bytes become data?
  - How does data become bytes?
  - How are unexpected symbols handled?
  - Does this code really implement the grammar as declared in the spec?
- Compare implementations at points of variance

Case Study: X.509

- Parse-tree differentials revealed multiple attack vectors:
  - Overflows (buffer *and* integer!)
  - Spurious NULL
  - Extra padding
  - Injection
- Parsing differences in both browsers, web servers, and CA software.

Subject Name Confusion

- X.509 Name = ASN.1 Sequence of Sets of Sequences of OID/String pairs
- Common Name only relevant one for browsers
  - Name of site being secured is compared against CN
  - If CA doesn't validate CN correctly, it will issue certs for names the user doesn't own

Multiple Common Names

- If a CN contains more than one Sequence of OID/String pairs, which one do we assume is the CN?
  - Spec doesn't say, formally.
  - OpenSSL: “Here, have a list of all of them”
  - CryptoAPI: “Here, have a list of all Strings matching OID 2.4.5.3”
  - NSS: “Here, have the last element of the sequence.”

Inefficient BER Encodings

- BER is complicated and lax, leading to multiple possible encodings for OIDs
- Leading-zero padding:
  - OpenSSL catches 2.5.4.03 internally but presents 2.5.4.3 textually
  - CryptoAPI: 2.5.4.[0]*3 == CN!
- Integer overflow:
  - CryptoAPI: $2.5.4.(2^{64}+3)$ == CN!
- Integer underflow?

Early NULL Termination

- ASN.1 strings are Pascal-style, not C-style
- CN=www.bank.com[NULL].badguy.com:
  - OpenSSL: www.bank.com\x00.badguy.com
  - Crypt::OpenSSL::X509: www.bank.com.badguy.com
  - OpenSSL X509_NAME_get_text_by_NID: www.bank.com
  - Firefox/IE: www.bank.com
- Moxie Marlinspike discovered this specific attack as well, through intuition.

OpenSSL compat mode injection

- OpenSSL can emit CNs as text from command-line
- Other scripts use this data, but it's ASCII
- Throw an escape character into a non-validated Name, e.g. organizationName:
    - ON=Badguy Inc/CN=www.badguy.com
    - Oh, look, the first CN we regex out is www.badguy.com, must be ok
- If you use command-line OpenSSL, use the nameopt flag.

PKCS#10-tunneled SQL injection

- In ASN.1 there are many types of String
  - BMPString: UTF-16, sort of
  - UTF8String
  - UniversalString
- Embed these in a PKCS#10 request, and you can embed any Unicode SQL injection attack you want

PKCS#10-tunneled ASN.1 attacks

- In 2002, PROTOS finds many, many ASN.1 vulnerabilities by way of SNMP
    - ... especially in BER
- Commercial CAs: was your ASN.1 BER parser covered?
    - We did not “test CAs' parsers for them,” that isn't nice.
- BER is so permissive, PROTOS might not have gotten everything
    - DER is much less complicated, and safer

Lessons Learned

- Language Theoretic Security is not just a defensive tool.
- Differential parse tree attacks are quite powerful
- The more ambiguity in a spec, the more attack vectors will be available
  - Yeah, that means you, ECMAScript and IPv6
- Cryptography is rarely the weakest link (again)

Security at the Language Level

- Postel's Law is outdated
  - Conservativeness in what you send is good
  - Liberalness in what you accept exposes you to attack
  - Attacker only needs to figure out what he can make you *think* he said
- “Mutually intelligible” dialects invariably lead to exploits

Context-free equivalence problem: a spanner in the works

- Determining whether two context-free (or stronger) grammars generate the same language is UNDECIDABLE
  - Except in the case where the rules and symbols of grammar G are a subset of those in grammar H
  - We proved that way back in 2005 (Dejector)
- Implementations that don't generate parsers from the specified grammar cannot be guaranteed to implement the grammar's language!

Grand plans

- Language validation shims at strategic locations
  - Network stack, kernel, hypervisor
- Protocols to be implemented with a reference grammar
- Canonical reference grammar specs, machine and human readable, used by the parser to validate different protocols dynamically
  - Protocols can be wire, file format, code execution format, etc.

Questions?

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